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A Chart for finding the Number of Lenses in, and Size of a Block.

By HORACE LEE, B.A.

(From the Research Laboratory, Messrs. Taylor, Taylor & Hobson, Ltd., Leicester.)

Read and discussed 13th June, 1918.

FORMULÆ for finding the number of lenses in a block have been given.* If α is the angle subtracted by a lens at the centre of the block, and θ is the angle with the vertical of a radius through the centre of a lens in a given ring,

then $$\sin\frac{\pi}{n}=\frac{\sin\alpha}{\sin\theta} \quad \text{and} \quad \sin\alpha=\frac{d}{2r}$$

where n=number of lenses in that ring, d and r being diameter of lens and radius of block respectively.

In the case of a block with one lens in the centre

$$\theta_1=0 \qquad \theta_2=2\alpha \qquad \theta_p=2(p-1)\alpha$$

with three lenses in the centre

$$\theta_1=\sin^{-1}\left(\frac{2}{\sqrt{3}}\sin\alpha\right) \qquad \theta_2=\theta_1+2\alpha \qquad \theta_p=\theta_1+2(p-1)\alpha$$

and so on for any number of lenses in the centre, but these two cases cover almost all actual cases.

The diameter of the block is given by

$$D=2r\sin(\theta_p+\alpha) \quad \text{or} \quad D/2r=\sin(\text{Ⓗ}) \quad \text{(say)}$$

For a flat block $r\to\infty$ or α and $\theta\to 0$, and so

$$\sin\frac{\pi}{n}=\frac{1}{2(p-1)} \qquad (p=2\text{ - - -}) \text{ in the first case}$$

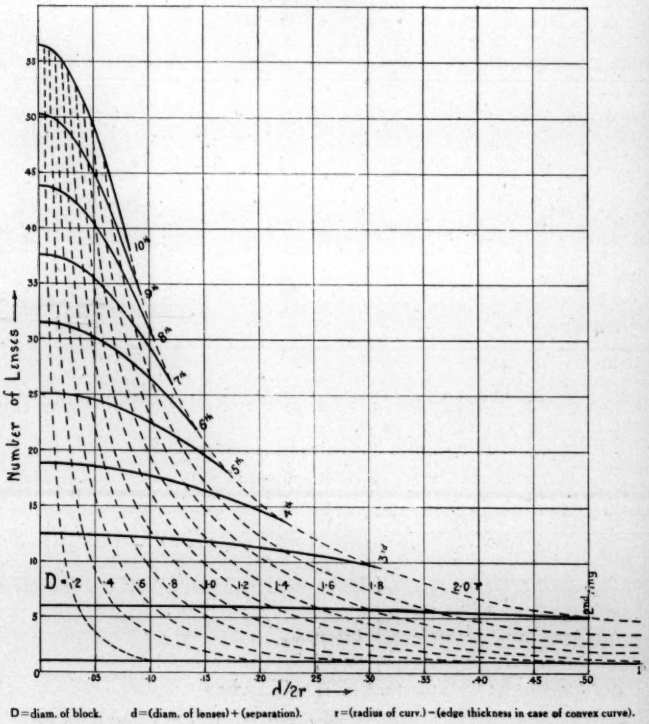
and $$\sin\frac{\pi}{n}=\frac{1}{\{2/\sqrt{3}+2(p-1)\}} \qquad (p=1\text{ - - -}) \text{ in the second case}$$

* The "Optician," Oct. 29th, 1915; Trans. Opt. Soc. 18 (1917), 56.

The method of constructing the chart is as follows :—In order that a hemispherical block should have p rings

$$\theta_1 + (2p - 1)\,\alpha = \frac{\pi}{2}$$

One Lens in Centre.



D=diam. of block. d=(diam. of lenses)+(separation). r=(radius of curv.)−(edge thickness in case of convex curve).

Fig. 1.

Explanation.—Find $d/2r$ on horizontal scale, and hold a straight-edge vertically through this point. The number of *full* lines cut is the number of rings, and the vertical scale gives the number of lenses in each ring. The position of the intersection of this vertical with the last ring, between two dotted lines, gives the diameter of the block.

This is solved in each case for α (in the second case by trial and error methods) for p having values 1, 2, 3, . . . 10.

Next a smaller block represented by $\sin \textcircled{H} = \cdot 9$ or $\textcircled{H} = 64° 10'$ is represented by

$$\theta_1 + (2p - 1)\alpha = 64° 10'$$

and α is again found for ten values of p.

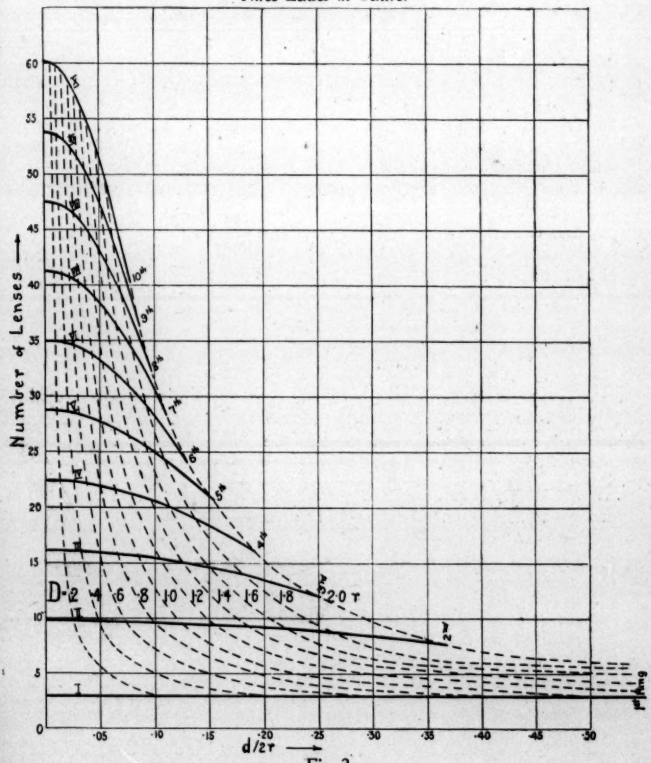


Fig. 2.

Finally the two sets of curves p = const. and $\textcircled{H}$ const. are shown, the former in full lines and the latter in dotted lines. These are done for the two cases of one in centre of block (Fig. 1), and three (Fig. 2). The equations of the curves are (n and sin α variables)

$$\sin\frac{\pi}{n}=\frac{\sin\alpha}{\sin\{\theta_1+2(p-1)\alpha\}} \qquad p \text{ const. and } \theta_1=0 \text{ or } \sin^{-1}\left(\frac{2}{\sqrt{3}}\sin\alpha\right)$$

and $$\sin\frac{\pi}{n}=\frac{\sin\alpha}{\sin\left(\textcircled{H}-\alpha\right)} \qquad \textcircled{H} \text{ const.}$$

For actual use these diagrams were traced and blue-prints made. In finding $d/2\,r$ the following corrections must be made:—Add to diameter of the lens the amount of separation in the block, subtract from r the edge thickness in case of a convex curve. Having found $d/2\,r$ a vertical line will show at once, by the number of full lines cut, the number of rings in any size of block, and the scale gives the number of lenses in each ring; where the vertical line cuts the last ring, the diameter is read off by the dotted curves; by interpolation between two dotted curves sufficient accuracy is obtained for any size of block. The extent of the scale to ten rings is more than sufficient to meet all likely cases.

DISCUSSION.

Mr. S. D. CHALMERS thought that Mr. Lee had put into a very convenient form what some workers had done in a less simple way. The charts would prove useful as they would do away with the necessity for elaborate calculations.

The PRESIDENT (Prof. CHESHIRE) said the charts should be hung up in workshops so that any workman could use them.

Charts for assisting in the Selection of Suitable Glasses for Cemented Doublets.

By T. SMITH, B.A.
(From the National Physical Laboratory.)

A METHOD of using two charts as an aid in the selection of pairs of glasses for cemented objectives free from spherical and chromatic aberrations and coma when used at a given magnification has been described by the author in a paper read before the Physical Society.* The charts shown here are used in a similar way, but instead of being constructed to give an exact solution to a definite problem, they are intended to serve as a guide to a manufacturer or computer in selecting a pair of glasses for any purpose. As this appears to be a rather wide claim to make, a short explanation may be given of the facts which justify it.

Objectives of the type considered can be calculated from expressions for the first order aberrations when thicknesses are neglected. The aberrations of such thin lenses are determined by three quantities which depend only on the relative powers of the two component lenses and on their refractive indices. One of these quantities is the Petzval sum, denoted by $\bar{\omega}$, and this does not change when the form of the lens is altered by adding a common increment of curvature to each refracting surface. The other two quantities are denoted by C_0 and $(B'_0 - B_0)$, which become C and $(B' - B)$ if the curvature of each surface is increased by some value, say r, when the focal length is unity. The relations between these quantities are

$$C = C_0 + r^2 (1 + 2\bar{\omega})$$

$$B' - B = B'_0 - B_0 + 2r (1 + \bar{\omega})$$

These three quantities $\bar{\omega}$, $(B'_0 - B_0)$, and C_0 thus determine the aberrations of every thin lens made from the same two glasses which have the same type of colour correction. Now $\bar{\omega}$ always lies within small limits, and $B'_0 - B_0$ is always small. On the other hand, C_0 varies over a wide range of values, and it is the variation in these values which gives the different character to the kinds of correction that are obtainable in different combinations of two glasses. In selecting glasses an average value of $\bar{\omega}$ may be assumed, and zero substituted for $(B'_0 - B_0)$ to a first approximation. All glass pairs which have the same value for C_0 when the required colour condition is satisfied can then be

* "The Choice of Glass for Cemented Objectives." Proc. Phys. Soc. 28 (1916), 220.

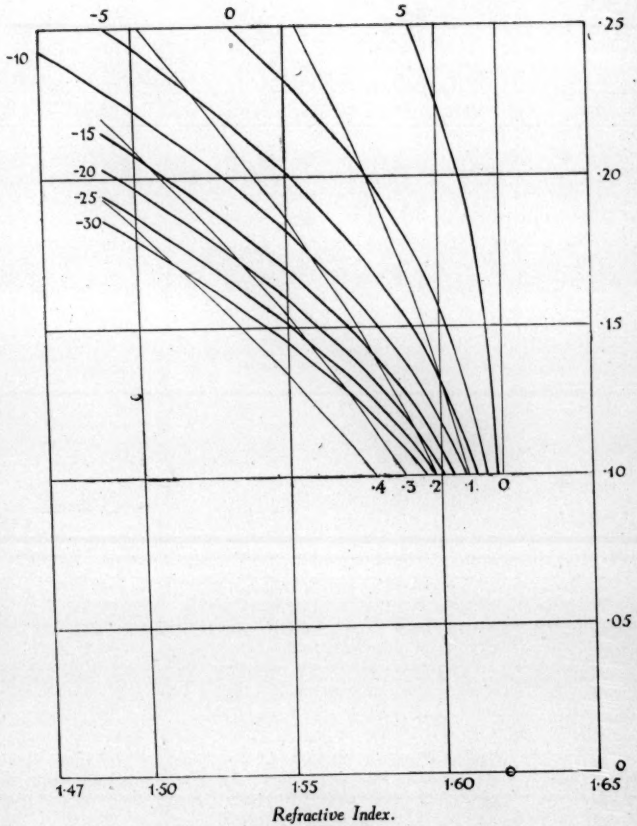


FIG. 1.—CHART FOR SPHERICAL ABERRATIONS.

substituted for one another and will enable the same types of spherical correction to be obtained within close limits.

In practice it is more convenient to take $4C_0+2\bar{\omega}+1$ as the variable instead of C_0, because C_0 always occurs in this form in the expressions for the first order aberrations of thin lenses. The conditions which have most usually to be considered in lenses of this type are those relating to spherical aberration and to coma. The first order latitudinal displacements due to these aberrations are proportional to

$$(1-m)^4\{4C+2\bar{\omega}+1-4(B'-B)M+(3+2\bar{\omega})M^2\}$$

and

$$(1-m)^3(1-s)\{4C+2\bar{\omega}+1-(B'-B)(3M+S)+\bar{\omega}M(M+S)+M(M+2S)\}$$

respectively where m is the linear magnification of the object produced by paraxial rays, s is the linear magnification of the stop similarly determined, and

$$M=\frac{1+m}{1-m}\quad,\qquad S=\frac{1+s}{1-s}\quad.$$

Thus if freedom from both aberrations is desired for $m=-1$, the conditions to be satisfied are

$$4C+2\bar{\omega}+1=B'-B=0$$

Since B'_0-B_0 is small, r will be small, and therefore C will be very nearly equal to C_0. Glasses may, therefore, be selected by imposing the condition

$$4C_0+2\bar{\omega}+1=0.$$

If more than one pair can be found which satisfy this condition equally well and there are no very obvious reasons for selecting one pair in preference to another (on such grounds, for example, as a greater difference in the ν values of the two glasses, leading to shallower surfaces), the selection may be determined by comparing the corrected conditions in which the actual values of $\bar{\omega}$ and B'_0-B_0 for the various pairs selected are substituted for the average value of $\bar{\omega}$ and for zero respectively.

Advantage is taken of this property of C_0 or of $4C_0+2\bar{\omega}+1$ in determining the types of correction that can be obtained by drawing curves connecting glasses having common values for this quantity. Since there are three variables—two refractive indices and the ratio of two powers—one of these must be fixed to enable a two dimensional diagram to be obtained. It is convenient to take the refractive index of one of the glasses as the fixed quantity. Since many lens combinations of widely differing character include a dense flint glass of refractive index about 1·62, one very useful chart has this as the fixed quantity. Such a chart is shown in Fig. 1. The refractive index of the other

glass is taken as abscissa, and the ordinate is the *logarithm* of the numerical value of the fraction

$$\frac{\text{power of lens of variable refractive index}}{\text{power of lens of fixed refractive index}}$$

The position of the fixed glass is represented in Fig. 1 by a circle near the lower right corner, and the thick curves correspond to glasses which

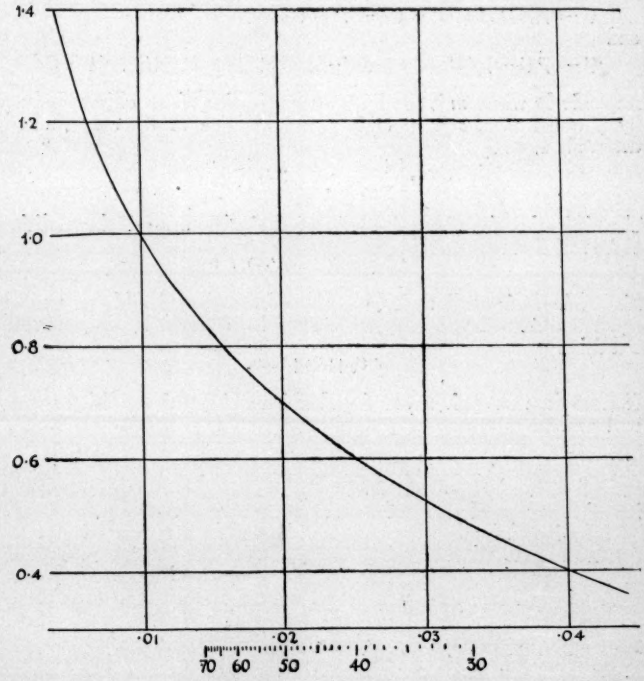


FIG. 2.—CHART FOR MAKING CHROMATIC ALLOWANCES IN CONSTRUCTING GLASS DIAGRAMS.

in combination with the fixed glass give values of $4C_0+2\bar{\omega}+1$ ranging from $+5$ to -30 in steps of 5. The thin curves give the values of (B'_0-B_0) in steps of 0·1 from 0·0 to 0·4. The curves are not continued for values of the logarithm below 0·1, as this region is of no practical interest.

Fig. 1 is used in conjunction with a second chart, such as Fig. 3, which is constructed from lists of the kinds of glass that are available. The chart shown in Fig. 3 shows glasses taken from a recent list of Messrs. Chance Bros. As before, the refractive index of the glass is taken as abscissa, and the logarithm of the ν as the ordinate. Glasses shown in the catalogue in thick type as standard varieties which can be supplied from stock are indicated by two concentric circles, and other kinds by a single circle. It is convenient to write by each circle the catalogue number of the glass to which it refers, but this has not been done in this diagram as the numbers may not print satisfactorily on the small scale to which the originals must be reduced. One of these diagrams—say the glass chart—must be drawn on tracing paper. This is then laid over the chart reproduced in Fig. 1, both having been drawn to the same scales, with the lines corresponding to the same refractive indices superposed. The second diagram may then be moved in the direction in which the logarithms are measured through any distance, so as to bring the reference circle of Fig. 1 and the circle representing any glass of refractive index 1·62 into coincidence. The other glass to be used to secure a given value of $4C_0+2\bar{\omega}+1$ in a cemented achromatic objective is then found by choosing the one whose representative circle most nearly falls on the line of Fig. 1 corresponding to this required value. The theory of this procedure is plain, and depends upon the relation

$$\log \nu - \log \nu' = \log \nu/\nu'.$$

From the use of the two charts described it is then evident that the relation $\nu/\nu' = -K/K'$ will be satisfied, where K and K′ are the powers of the component lenses. The compound lens will thus be achromatic. It is obviously essential that charts to be used in this way should have as ordinates the logarithms of the fundamental variables, rather than the values of the variables themselves.

If this were the only use that could be made of the charts there would be very little justification for the labour of constructing them. Two facts, however, render it possible to use them in a much more general way. The shapes of the curves shown in Fig. 1 do not vary rapidly as the fundamental refractive index is changed, so that the one chart may be used for any fundamental refractive index which does not differ very considerably from 1·62. Three charts, for instance, should prove

FIG. 3.—GLASS CHART FOR ACHROMATIC OBJECTIVES.

ample for the whole range of refractive indices available for ordinary purposes. This means that the glass chart may be given a displacement in the direction in which the refractive index is measured relative to that on which it is placed, so that instead of requiring the straight lines corresponding to a common index to be superposed it is sufficient that

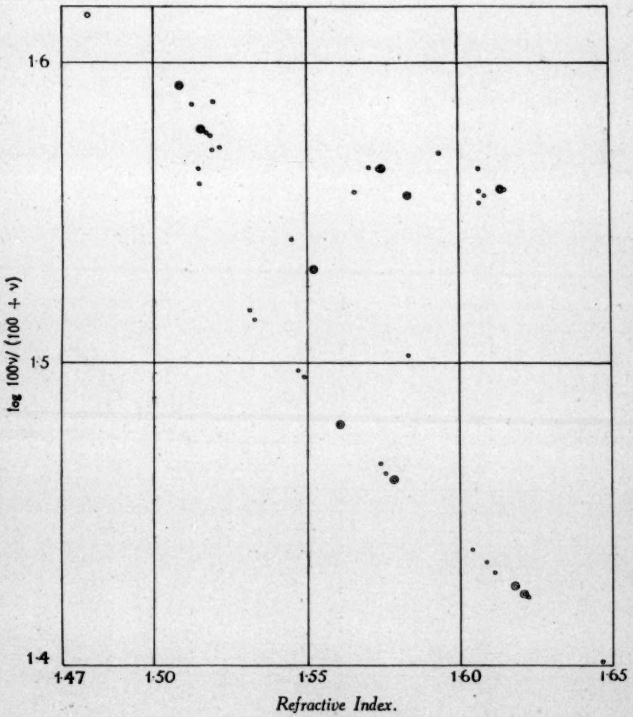


FIG. 4.—GLASS CHART FOR OVERCORRECTED CHROMATIC ABERRATION.

they should be parallel to one another. Fig. 1, for example, may be used for any glass combination in which any dense flint is used.

The second consideration is that by substituting for Fig. 3 another diagram in which the ordinates are changed, any required amount of chromatic aberration may be introduced without affecting the spherical corrections. The relation to be satisfied by components of powers K and K′ made from glasses with ν values ν and ν' to make the power of the combination for the F line exceed that for the C line by one n^{th} part of the power for the D line is

$$-\frac{K}{K'}=\frac{\nu\,(n-\nu')}{\nu'\,(n-\nu)}\,.$$ *

This shows that the glass chart must be so constructed that the ν of any glass is replaced by $\left(\frac{1}{\nu}-\frac{1}{n}\right)^{-1}$. Fig. 4 shows the glasses of Fig. 3 replotted for $n=-100$, corresponding to very heavy over-correction of the chromatic aberration, instead of $n=\infty$, the value for normal colour correction. Such a chart is very easily plotted for any required value of n by direct calculation. An alternative method is to use Fig. 2, where the ordinates are the logarithms of the reciprocals of the abscissæ, for which both a uniform and an inverse scale are provided. If an achromatic objective is required, the ordinates for Fig. 3 are read from the curve of Fig. 2, taking the lower scale reading corresponding to the ν of the glass. If the dispersive power from F to C is to be $1/n^{th}$ of the power for the D line, the abscissa selected is on the upper (uniform) scale a distance $\frac{1}{n}$ to the left of the ν value given by the lower scale, and the corresponding ordinate is to be plotted on the glass chart. Thus Fig. 4 would be obtained by displacing the ν scale through the distance ·01 to the right, measured on the upper scale, and using the modified ordinates so found as the ordinates in Fig. 4.† In this way, Fig. 2 enables a glass chart to be constructed for any required degree of chromatic under or over correction.

In this discussion reference has been made to the indices and dispersions for the C, D, and F lines. This is done simply by way of illustration. Figs. 1 and 2 are quite independent of any such assumption, and in plotting the glass charts any desired interpretation can be given to the quantities ν and ν'. The glasses must be plotted for the refractive

* This may be verified by noting that $K+K'=1$ and $K/\nu+K'/\nu'=\frac{1}{n}$ if $K=\frac{\nu\,(n-\nu')}{n\,(\nu-\nu')}$ and $K'=-\frac{\nu'(n-\nu)}{n\,(\nu-\nu')}$.

† It will be noticed that Fig. 2 is not drawn on the same scale as Figs. 1, 3, and 4. In use the same scale should be employed.

index corresponding to the line of the spectrum for which the spherical conditions are to be applied.

By the use of such charts much time can be saved in calculating simple cemented objectives, since it is possible to ascertain beforehand that the glasses selected will be the most suitable of those that are available. Apart from such a method, only previous experience will enable a computer to avoid making calculations with a number of pairs of glasses, and after all having no result to show for his labours owing to the impossibility of meeting the various conditions that have to be satisfied with the pairs he has selected. This appears to be the direction in which the computer has hitherto had least systematic guidance. If a manufacturer knows that a certain effect has been obtained with certain glasses which are not now available, he can at once find what new combinations to take to secure a very similar result by using the charts to find the value of $4C_0+2\bar{\omega}+1$ for the old combination, and then performing the reverse operation with the glasses that can be obtained, selecting the pair that comes nearest to the old value of this quantity. The proper curvatures for the surfaces of the new lens will then be found in the usual way.

Formulæ for the calculation of the fundamental quantities referred to above will be found in the Physical Society paper to which reference has already been made, or they may be derived from formulæ previously given to the Optical Society* by making C a minimum as r is varied.

DISCUSSION.

Mr. S. D. CHALMERS said he was interested to see how Mr. Smith had developed his work by using charts. He himself had made use of a somewhat similar method. Another defect in the list of glasses was the absence of Medium Barium Crowns having a lower value of ν than at present. The principal interest in the charts lay in the fact that they saved a great deal of analytical work. In some cases, however, the results would require to be examined in detail as correction terms might have to be introduced.

The Author, in reply to a remark by Mr. Beck, said the charts related to the removal of first order coma. The effect of small errors would not increase the number of glasses available when good correction for more than one aberration had to be obtained. The same charts could be used for any of the first order aberrations, such as distortion, curvature, etc.

With regard to Mr. Chalmers' remarks he would like to point out that the charts contained a series of lines which allowed a correction to be applied to the first approximation if necessary.

* Trans. Opt. Soc. 17 (1917), 160.

On the Prevention of Film in Enclosed Optical Instruments.

By H. S. RYLAND.

Read and discussed 13th June, 1918.

In every type of enclosed optical instrument, instances, more or less frequent, of "film" will be found. By film is meant the coating of lens and prism surfaces with what is apparently a thin deposit of moisture. This has caused much trouble and annoyance, many instruments being rendered quite useless until taken apart and cleaned. The film appears to have several characteristics. It apparently consists of a series of globules of moisture, forming patterns on the surface similar to those made by cleaning with a linen rag which has seen long service. Often a series of larger globules will occur, each surrounded by a clear space. Parts of a surface under pressure from mounts will be clear for a small space surrounding the points of contact, the clear space being fringed by a denser deposit. Prisms will often show a distinct pattern of the seat, the part covered by metal having a fairly dense deposit, a fairly clear space occurring where the surface is free, becoming again more dense away from the metal. A cut, scratch or hole in the surface is generally surrounded by a clear space beyond which again the deposit is more dense.

If a drop of distilled water from a pipette is allowed to run over a filmed surface, it will leave a track which is quite free from any trace of scum. Microscopic examination shows no trace of injury to a surface after filming. Instruments such as telescopes, in which the air is occasionally changed, very seldom film. Where they do so it is generally the case that they have been out of use for some considerable time.

A number of experiments have been tried in order to determine the cause of film. Certain types of black, notably the japan black and those containing pitch or bitumen, almost always cause film; aluminium machined and not cleaned afterwards; a small trace of animal matter or beeswax in the enclosed space will give trouble.

With a well cleaned case, however, and even when prisms alone were well cleaned and placed under a clear bell jar, *some* cases of film would occur. This was found to be caused apparently by the trace of soap which is more often than not left in the linen used for cleaning, even after careful washing.

The following precautions have been found in all experiments to eliminate film completely:

(1) No japan or bitumen black to be used on interior surfaces.

(2) No pitch or beeswax to be used within the case.

(3) All interior surfaces must be thoroughly cleaned and free from animal matter such as finger marks. In the case of aluminium or other porous metal, heat treatment is necessary after machining, to remove all trace of grease.

(4) The lenses and prisms after ordinary cleaning to be dipped in hot running water with a pair of tweezers, and wiped dry with clean linen [see (5) and (7)] without being touched by the fingers again.

(5) After washing the linen used for cleaning purposes, it must be well rinsed in running hot water till all trace of soap has gone.

(6) Dust must be removed with a clean camel hair brush and not by blowing.

(7) The linen used for cleaning must be used in such a way that no part of it which has been touched by the fingers is brought into contact with the lens or prism surface.

(8) All surfaces must be well polished and free from " orange peel " effect. If the pitch polisher leaves a trace of scum, a small quantity of glacial acetic acid added to the pitch when melted will prevent it.

The use of these precautions will apparently make even poor glass remain free from film. Different glasses however appear to have different susceptibilities to film; the most troublesome glass I have found to be one made of Boro-Silicate Crown. Careless moulding, too, will at times cause trouble. I have found in several instances that a prism cut in half and polished on the cut surface will scum badly on the exterior surface, while the interior remains clean. I hope and think that the use of the precautions outlined will save much trouble and expense. A simple check on the workpeople is to breathe lightly on a surface, and if it shows a " wiping pattern " it will eventually film.

DISCUSSION.

Mr. JAMES W. FRENCH communicated the following remarks :—

The word " film " suggests a continuous layer. To maintain a continuous layer of water on a polished glass surface is difficult. Minute points, microscopic sleeks, and defective cleaning marks break the film, which gathers into minute globules under the action of surface tension forces. Adjacent globules may coalesce, leaving a surrounding clear space, as described by Mr. Ryland, but this appearance corresponds with that of fogging, which is already well known. It seems inadvisable to introduce such a description as " filming," which almost suggests a mystery where possibly none exists.

Most probably the globules are composed of water contaminated more or less with grease. The fact that the fogging can generally be reduced by desiccation suggests water vapour. If the amount of grease present in the water were considerable, evaporation might result in globules of oil, such as were reported on one occasion. It is important to know what the globules are composed of originally. If due to water they can easily be dealt with by desiccation ; if due to oil, the problem is more difficult.

Personally I believe they are due to water contaminated according to circumstances. Water vapour is everywhere and ready to settle out on the slightest provocation. Volatile oils are not so universally present. They have generally been distilled away in the preparation of the substances. Even the stoving of metal bodies should be sufficient to eliminate such volatile oils as could settle out at normal temperatures and pressures. Beeswax, vaseline, and kindred materials often contain much water, but they are easily freed from water and other low tension vapours, and they ought to be so treated before use, if trouble is to be avoided.

Mr. Ryland has confined his attention more to those circumstances that bring the fogging into prominence than to the cause. It might be well to consider the possibility of removing the cause itself, because if there is present confined air saturated with moisture, there will be danger of fogging, no matter what precautions are taken.

Some of the members may not have given desiccation their particular consideration, and a few remarks on the subject may not be inappropriate. The more air is heated, the more moisture it can carry. When saturated air is cooled, the excess moisture is precipitated. Where the moisture will form depends on many factors, such as the specific heats of the materials, nature of surfaces, existence of minute local air currents, and so on. To heat open binoculars and then close and seal them is worse than useless. A warm summer day may not be best for drying purposes. A dry, cool temperature is the best ; the dryness should be observed by means of a hygrometer. Mild circulation of the air reduces the time of drynig. Calcium chloride, phosphorus pentoxide, and sulphuric acid are good drying agents. The first substance is the safest to use in instrument work. The calcium chloride may be placed in metal trays and flexible metal tubes may be used as connections. The complete but open binoculars should be placed in a stove connected in series with a hand or motor-driven pump and a calcium chloride container. The circuit should be a closed one ; that is, the same air should be circulated. Quarter of an hour to twenty minutes should be ample for a stove of 8 cubic feet, assuming the parts are not initially really moist. The instruments should be kept in the neighbourhood of the dry air while being closed down preparatory to sealing.

In the case of large optical instruments, desiccator connections should be provided, because, although instruments may be thoroughly desiccated and sealed before despatch, they may be opened out in service. In the case of an instrument such as a periscope having an internal capacity of about five cubic feet, about twenty minutes is required to remove all signs of heavy fogging on the interior surfaces of the top window and parts, when the circulating pipe is led into the head. If complete circulation is not arranged for, the time of drying is increased, say, to half or three-quarters of an hour. A mass of dry air will draw the moisture from surrounding air. Circulation, as is to be expected, accelerates the drying process.

The calcium chloride can be arranged in a nest of trays, the air being caused to pass over as great a surface as possible. Efficient drainage should be provided, but the calcium chloride should be renewed before it becomes very moist. The drying of a large fogged instrument will hardly appreciably moisten a pound of calcium chloride.

I presume Mr. Ryland does not mean that a greasy finger mark will cause fogging. Its importance, I presume, lies in the fact that it is an indication of general carelessness and want of cleanliness. In optical work scrupulous cleanliness should be studied. The benches should be clean and free from all exposed and concealed litter. The parts should

be arranged in neat boxes. Only those tools to be used in the particular operation should be given out. Unless scrupulous cleanliness is exercised throughout, all kinds of troubles are likely to arise.

Mr. Ryland has performed a most useful service in having brought this important subject forward so that the many diverse opinions may be discussed and recorded.

Additional Note.—I would like to remark particularly that in emphasising the need for scrupulous cleanliness in the cleaning of optical work I took it for granted that the instrument is really desiccated, and that all possible water vapour has been removed. In Scotland our naturally damp atmosphere makes the efficient desiccation of optical instruments a matter of the greatest importance. The great majority of our optical instruments are provided with suitable connections for special desiccating apparatus. All small instruments are thoroughly desiccated internally before being sealed up. In many small instruments, such as binoculars, it is not practicable to provide them with desiccating attachments.

Mr. CONRAD BECK said that Mr. Ryland's paper described an investigation on the cause of film on glass which was very interesting, and most important to complete. It was essential to ascertain whether one kind of glass or another is more liable to become fogged over with film, and if possible to ascertain the reason. He understood that the film referred to is the film that can be removed by wiping, and not a permanent alteration of the surface; but in the interest of such an investigation we must not be carried away from the main and obvious cause of the trouble.

When a ray of sunlight passed into a badly illuminated room, we had forced on our attention what we were otherwise tempted to forget, that the atmosphere is saturated with millions of particles of dust. Moisture in the air had a tendency to accumulate on these particles of dust, and when water was deposited by a sudden change of temperature upon a surface it carried the dust down with it. On evaporation the dust was left behind, and it could be seen that the windows of the lecture theatre were covered with a scum which is known now as film. When this interesting and important investigation as to the cause of the sort of film which is not due to this simple and obvious cause had been completed, we should find we had perhaps 90 per cent., perhaps 99 per cent. of the film trouble still to be considered.

There was some evidence to show that film does not deposit inside optical instruments except in the presence of moisture. The Admiralty informed him that they have never met with it inside submarine periscopes which are hermetically sealed to stand a pressure of several atmospheres, and which are filled with absolutely dry air. He was told that it had not been met with in the Aldis Unit Sight when properly sealed, except in some experimental cases when a coating of glycerine had been placed on the internal surfaces to pick up floating dust particles.

His firm polished 15 plates of different glass, including three types of Schott and Gen. glasses made before the war, and a number of those of Chance, Mantois, and Graillot, plate and spectacle crown. These were let into a wooden panel which formed the lid of a partially closed box, and by warming the box to about 120° F., and then placing the box in the air, a heavy film was produced and the interesting point was that it was produced on every kind of glass. Whether the nature of the deposit was the same in all cases had not yet been determined, as the panel had been sent to Sir Herbert Jackson for investigation; but every kind of glass was so badly filmed that its use in optical instruments would be disturbed.

When Mr. Ryland said that he had by special methods of cleaning cured the defects, he (Mr. Beck) was unconvinced as regards the deposition of dirt by moisture. His firm had tried all methods of cleaning, and he considered that all that could be expected of such methods is that the surface may be to a slight extent rendered more or less liable to a deposit.

With regard to the question of this being a new defect, what should be said was that it is a defect newly discovered by some testing laboratories.

The optician had had instruments regularly returned to him in the past for cleaning, and had looked upon it as a necessary and incurable result of a damp atmosphere. Mr. Ryland had found in opticians' shops foreign field glasses (which must have been made at least as long ago as before the war) which had film on the interior surfaces, and since the matter had been brought into prominence, telescope object glasses made many years ago have been examined which had film on the uncemented contact surfaces.

While not wishing to discourage the investigation of the properties of glass and cleaning processes, he was strongly of opinion that far more should be attempted in the design of instruments, to reduce the number of internal surfaces, to totally exclude air, or to make it easy to wipe all internal surfaces without injuring the adjustments of the instruments.

Dr. R. S. CLAY drew attention to the fact that, when air is cooled, moisture does not condense unless nuclei are present. Each particle of dust, or a sharp point, may act as a nucleus on which a drop of water will form. This may be the reason why filming is greater on sleeks and less on the immediate neighbourhood. It might be advisable to filter the air of the assembling room by passing it through a grid covered with sheets of cotton wool to remove the dust particles. He thought Mr. Ryland's results were not really at variance with Mr. Beck's remarks.

Mr. S. D. CHALMERS thought that there was more than one type of film. In some cases a thin oily layer is present, and when dirt reaches this globules are formed. Mr. French's method depends on the exclusion of dust rather than of moisture. The presence of oil is due to the substances used for protecting the glass surfaces during subsequent processes. The spirit used for cleaning purposes is not so free from oily substances as formerly. Frequently the surfaces are spoiled by acid which leaves points on which deposition takes place.

Dr. R. S. CLAY said that a very small quantity of oil will spread over a large surface of water, and thus, if the surfaces were not free from grease, the deposited moisture might become covered with a thin layer of oily matter which would prevent the film from evaporating —just as the London fogs are prevented from dissipating by the oil on the drops of water, and have to be blown away or allowed to settle on the ground.

Mr. WILLIAM GAMBLE said there was a difference between filming and steaming. Difficulty is experienced in photographic process work owing to the presence of acid fumes, ammonium sulphide, &c., in studios causing filming. In cold weather men who work the wet collodion process find trouble from "sweating" of the screen placed in front of the moist plate. This is cured by rubbing the screen with glycerine or the screen may be coated with thin gelatine. An old-fashioned cure is to place a hot brick wrapped in flannel inside the camera.

Some optical surfaces pick up moisture more readily than others; a surface of Iceland spar, for instance, will do so more quickly than glass. Some workers find the addition of iodine to the alcoholic solution used for cleaning glass surfaces advantageous.

One of the best methods of drying air is to cause the moisture it contains to be deposited by chilling in a refrigerating chamber, and then to heat it. This method might prove advantageous before sealing air-tight optical instruments.

The PRESIDENT (Prof. CHESHIRE) thought that insufficient attention was paid to the original cleaning of the surfaces. He had seen the elaborate cleaning processes used by Zeiss. They began by soaking the prisms in potato spirit, and after several intermediate processes, of which he had forgotten the details, finished up by rubbing a pitch stick entirely over the surfaces three times in succession. Chemical cleanliness was not attained in the workshop

to the extent that was thought. He was reminded by one of Mr. Gamble's recipes of a preparation he once came across which was guaranteed to be a perfect preventive of clouding of eye-glasses. It was sold in the form of a pencil of delicate scented matter, and the protection was secured by rubbing it generally over the surface of the glasses. This remarkable preparation turned out on examination to consist of Pears' soap.

The AUTHOR, in reply to Mr. French, pointed out that "film" could be produced on any surface by smearing it with soap, removing it by wiping, and breathing on the surface. If the term "film" suggests a mystery it is well, for it has been a source of trouble for three years, and is still. Instruments afflicted with "film" have been heated by the author, and, while in some cases no perceptible change took place, in others there was an improvement; but in every case some characteristic "film" remained. "Film" was always progressive.

Mr. BECK said this did not agree with the results obtained at Woolwich.

Mr. RYLAND, continuing, said that in the experience of Woolwich "film" was progressive, and in every case which had come under his own observation it was definitely progressive. He had not found dust particles contained by the film globules. He was glad to hear Mr. Beck's suggestion that instruments should be designed so as to be taken apart for cleaning, and he pointed out that the design must be such that adjustment was automatic. It would be better, however, for manufacturers to take the necessary precautions to avoid "film."

In reply to a remark by Mr. Whipple he said it was found that at least in one case where eyepiece grease was suspected, the trouble was caused by want of cleanliness.

Replying to Mr. Chalmers, the author pointed out that however fine or thin the deposit appeared to be, it could, with suitable illumination, be resolved into the characteristic globules. Further, a "fine" deposit sooner or later became dense.

Finally the author pointed out that in his experience want of cleanliness, both in assembling and in the linen or silk used, invariably caused film; he also described the various articles, such as metal turnings, small particles of food, etc., found in sealed instruments, and asked those responsible to try the methods he had described for the avoidance of this very serious trouble.

Discussion on "Filming of Glass,"

held by the British Optical Instrument Manufacturers Association.

We are indebted to the British Optical Instrument Manufacturers Association for a report of a Discussion on the "Filming of Optical Glass," which took place at a meeting called by them for this purpose. From this report the following abstract has been prepared, which it will be of interest to Members of the Optical Society to read in connection with the preceding paper.

The chief points of interest that were brought out in the discussion are as follows :—

(1) Two kinds of film are met with : (*a*) a more or less globular film which is alkaline, and (*b*) a film which is largely organic in nature and is due to condensation around nuclei (such as dust particles) or pits on the surface of the glass.

(2) Usually the graticule is at fault, though this may partly be due to the fact that film on the graticule would to an observer be in focus and therefore more noticeable than in the case of other surfaces.

(3) In some instances film increases with time.

(4) Generally speaking, glasses showing the greatest affinity for water give the most trouble.

(5) The chemical constitution of the lubricants used in optical instruments appears to have a very important bearing on the subject.

(6) Film is sometimes probably due to the presence of traces of hydrochloric acid which has been used in pickling the castings.

Difference of opinion was expressed with regard to (1) the question of the superiority of German glasses and (2) the adequacy of the iodeosin test in determining the relative predisposition of different types of glass to film.

Stress was laid on the following important precautions to be taken in order to prevent or reduce to a minimum the formation of film :—

(1) Care should be taken in the choice of glass. Hygroscopic glasses should be avoided.

(2) Absolute cleanliness in every detail is essential.

(3) The air of the rooms in which optical instruments are assembled should be thoroughly dried and freed from particles of dust.

(4) A high quality of polish is requisite, as small pits, scratches, etc., on the surface tend to act in the same way as dust particles, namely, as nuclei around which film is deposited.

It was suggested that :—

(1) Investigations should be carried out in order to find, if possible, a more suitable grease, one that is free from unsaturated compounds, to be used as a lubricant in optical instruments.

(2) Better ventilation between the different chambers of an instrument should be provided.

(3) Optical instruments should be so designed as to permit of easy access to the glass surfaces for the purpose of cleaning.

The results of tests on 17 samples of different types of glass were submitted; they are given in the table below.

TEST 1.—The alkalinity of a freshly broken surface which has been weathered for 7 days in an atmosphere at 180° C. saturated with water vapour was measured, the number of mgms. of iodeosin precipitated on 1 sq. metre of surface being taken as a measure of the weathered alkalinity.

TEST 2.—The glass was subjected for 30 hours to the action of clean air at 80° C. saturated with water vapour, and the deposit on, or corrosion of, the surface was examined microscopically. The glasses were graded according to the following qualitative classification:—

CLASS 1.—Unaffected, or only slightly affected.

CLASS 2.—Decidedly affected.

CLASS 3.—Very seriously affected.

For glasses coming between the classes, + indicates that the glass was rather more and − that it was rather less affected than the standard for the class.

Sample.	Maker.	Type.	Melting.	n_D	ν	Result of Test.	
						1	2
0	Schott & Gen.	H.F.	O. 5916	1·6241	35·7	37	2
1	Chance	B.S.C.	3401	1·5078	64·0	24	2−
2	Schott & Gen.	B.S.C.		1·5188	60·4	36	2+
3		Spectacle Crown				43	2+
4	Schott & Gen.	B.L.F.		1·555	48·2	60	2+
5	Graillot	B.L.F.	1056	1·559	50·6	12	1+
6	Chance	B.L.F.	3684	1·5503	51·8	28	2
7	Chance	H.C.	3504	1·5163	60·5	26	2
8	Chance	M.B.C.	3359	1·574	57·7	6	1+
9	Schott & Gen.	B.S.C.	O. 7302	1·5765	64·0	6	2
10		Plate				28	3
11	Chance	L.F.	1044	1·5791	40·5	17	1
12	Mantois	L.F.	9040	1·574	42·7	13	2
13	Chance	H.F.	3867	1·6211	36·2	12	1
14	Chance	H.F.	3621	1·6223	36·1	11	2
15	Chance	Soft C.	3532	1·5138	56·9	52	3
16	Graillot	E.D.F.	1126	1·652	33·6	11	1+

Note by E. M. NELSON on the paper "Relative Dispersion and Achromatism," by F. E. LAMPLOUGH, M.A., and I. MAUD MATHEWS, Trans. Opt. Soc. 19 (1918), 83.

In the discussion on Mr. Lamplough's paper on an electromagnetic dispersion formula Col. Gifford mentioned my dispersion formula. The results of the application of both formulæ to Dr. Hopkinson's * measurements of Chance's glasses are given in the following tables:—

ERRORS OF F. E. LAMPLOUGH'S FORMULA.†

Data : Lines C and F.

Lines.	Hard Crown.	Soft Crown.	Extra Light Flint.	Light Flint.	Dense Flint.	Extra Dense Flint.	Double Extra Dense Flint.
B	+ 17	+ 47	− 09	− 55	− 99	− 123	− 172
D_2	− 16	− 9	− 35	− 86	− 160	− 212	− 273
E	− 12	− 25	+ 49	+ 69	+ 159	+ 213	+ 321
G′	− 72	+ 01	−175	−337	− 604	− 720	−1153
H′	+195	+ 03	−504	−916	−1663	−2111	—‡

The terminal figures are in the 6th decimal place.

Analysis: 18 lines have an error in the 4th decimal place, including 3 with an error in the 3rd decimal place.

Maximum error − 0·002111. Maximum range of error 0·002432.

		Wave-Lengths.		
B	....	6867·461	....	−0·108412
D_2	....	5890·182	....	+0·294956
H′	....	3968·62	....	+2·147490

ERRORS OF E. M. NELSON'S FORMULA.‖

Data : Lines C and D_2.

Lines.	Hard Crown.	Soft Crown.	Extra Light Flint.	Light Flint.	Dense Flint.	Extra Dense Flint.	Double Extra Dense Flint.
B	− 14	− 13	− 18	− 45	− 61	− 65	− 89
E	− 30	− 85	− 23	− 72	− 90	−111	− 51
F	− 28	− 66	+ 07	− 12	− 51	− 85	+ 19
G′	+ 01	− 69	+ 80	+ 99	+ 60	+ 90	+266
H′	+ 23	−104	+ 61	+123	+ 28	− 01	—

The terminal figures are in the 6th decimal place.

Analysis : Errors in 3rd decimal place, nil. Errors in 4th decimal place, 4.
Maximum error, +0·000266. Maximum range of error, 0·000377.

Dr. Hopkinson's measurements were made with a spectrometer constructed by Sir Howard Grubb. The objectives of the collimator and telescope were of 2 inch aperture. The arc was 15 inches in diameter, and the reading made by two verniers to 10″. The first five glasses had 3 angles measured, the sixth 1, and the seventh 2.

* Proc. Roy. Soc., 26 (1878), 290. † Trans. Opt. Soc., 19 (1918), 83.
‡ Dr. Hopkinson did not measure H′ of the Double Extra Dense Flint Glass.
‖ Jour. Roy. Micr. Soc., Apr., 1899.

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